# THE CYGNUS X COMPLEX

*by*

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# THE CYGNUS X COMPLEX

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*Summary*

Detailed observations of the Cygnus X region have been obtained at a frequency of 3200 Mc/s using the 10-metre parabolic reflector of the National Research Council of Canada. The resultant contour map shows this region to be very complex, having more than thirty bright condensations. A flux density has been computed for each and an angular size has been estimated for all sources larger than twenty minutes of arc. Of particular interest is the strong source at right ascension $20^{h}\,21^{m}\cdot 2$, declination $40°\ 08'$, presently known as the $\gamma$-Cygni source. A derived spectral index of $-0\cdot 4$ and its large angular size lead to the hypothesis that this source is the remnant of a type II supernova at a distance of 300–1650 parsecs.

1. *Introduction.*—In the summer and autumn of 1962, a survey of the Cygnus X region at a wavelength of 9·4 cm was undertaken by the National Research Council of Canada. The 10-metre parabolic reflector at the Algonquin Radio Observatory was used as a meridian transit instrument, allowing one scan of the region each day.

The survey was undertaken partially as an operational trial of the receiving system, and partially due to a recent renewal of interest in Cygnus X. Undoubtedly the major part of the radiation from this complex region arises from H II emission, but there exists some evidence (1, 2) of a non-thermal component. In fact, it has been suggested (3) that the $\gamma$-Cygni radio source may be a supernova remnant similar to the Cygnus Loop.

2. *The observations.*—At 3200 Mc/s, the antenna has a half-power beamwidth of $37'\cdot 6$, and the area of 160 square degree was covered in about 150 scans. This area, defined by right ascensions ($\alpha$) of $20^{h}00^{m}$ and $21^{h}15^{m}$, declinations ($\delta$) of 36° and 47°, included most of the Cygnus X region, while excluding the strong source Cygnus A. The daily scans were made at intervals of 15′ in declination, several being taken at each position.

The travelling-wave tube receiver used for this investigation was of the Dicke-type, similar to that used by Broten and Medd (4, 5, 6) for earlier investigations. With a band-pass of about 250 Mc/s, and a post-detection time constant of 2 seconds, the r.m.s. noise fluctuation was about $0°\cdot 1\ T_A$ (antenna temperature). The radiometer output was recorded in standard analogue chart form.

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At the beginning and end of each drift scan, a calibration signal of known equivalent antenna temperature was injected into the antenna branch of the receiving system. This permitted the conversion of the records to values of antenna temperature above the background value at $\alpha = 19^h30^m$ and $21^h20^m$. This background level, for such regions away from the galactic plane, has been estimated to be less than 0·1 °K at a wavelength of 9·4 cm (**6**).

3. *Analysis of observations.*—Of the 150 drift-curves taken, 8 per cent had to be discarded and a further 25 per cent were classed as poor. This was due to either poor weather or malfunction of the equipment. During the course of the observations, it was found that aside from long-term temperature drifts in the records (of an elusive nature), shorter-term variations with a period of approximately 40 minutes were being introduced due to the thermal cycling of the waveguide run from the feed horn to the radiometer. The following method of analysis yielded approximate corrections to the daily drift-curves for the thermal cycling and long-term drifts.

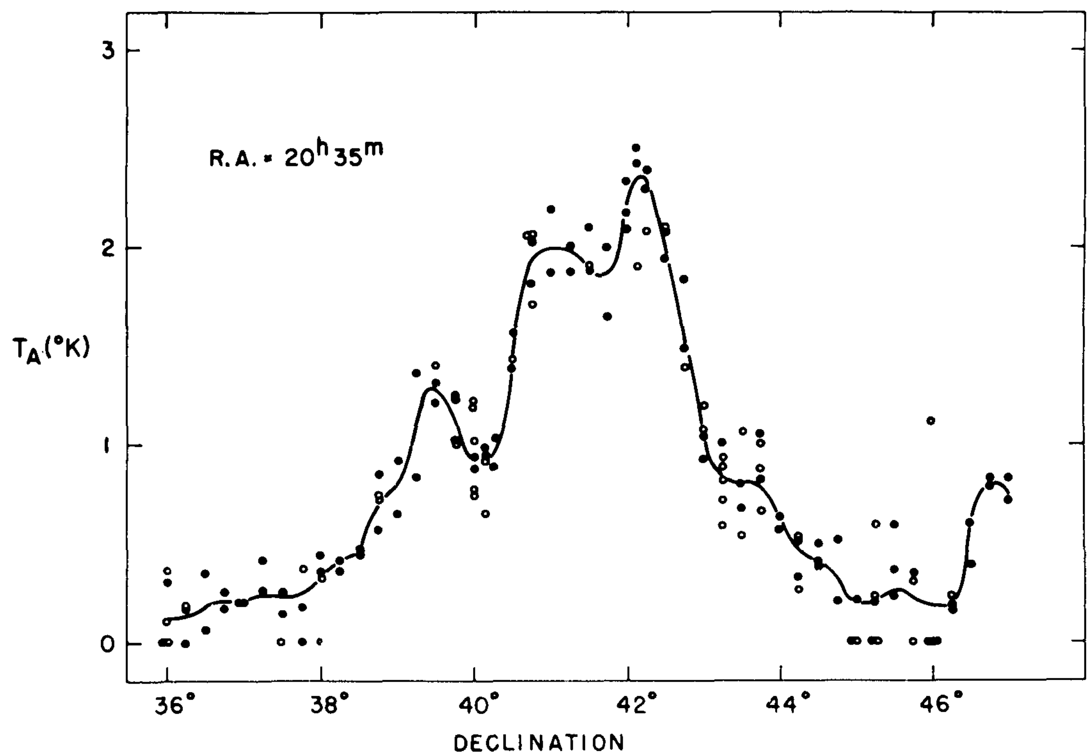


FIG. 1.—*Uncorrected observations at a given right ascension and adopted reference profile. Open circles denote poor observations, filled circles denote good observations.*

Using all the observed drift-curves, antenna temperatures as a function of declination were plotted at each of a set of right ascensions at intervals of $5^m$. For each such plot, a smooth reference profile in declination was drawn after assigning weights to the observations. Such a plot is shown in Fig. 1. The difference ($\Delta$) between values given by these reference profiles and the observed values of antenna temperature for each drift-curve should show any cyclic fluctuations or long-term non-linear drifts. Examples of these for two representative runs are shown in Fig. 2.

Smooth curves of Δ were drawn for each drift-curve and these corrections were applied to the original observed values. For each declination, all corrected curves were then averaged together yielding a mean drift-curve. Finally, these were combined into a contour map of the region. The co-ordinates of this map were corrected for precession and also for the deviation of the antenna beam from the geometric axis of the telescope. The latter was determined from observations on Cassiopeia A, Cygnus A and Taurus A and was found to be 5′·1 northward in declination and to be negligible in hour-angle.

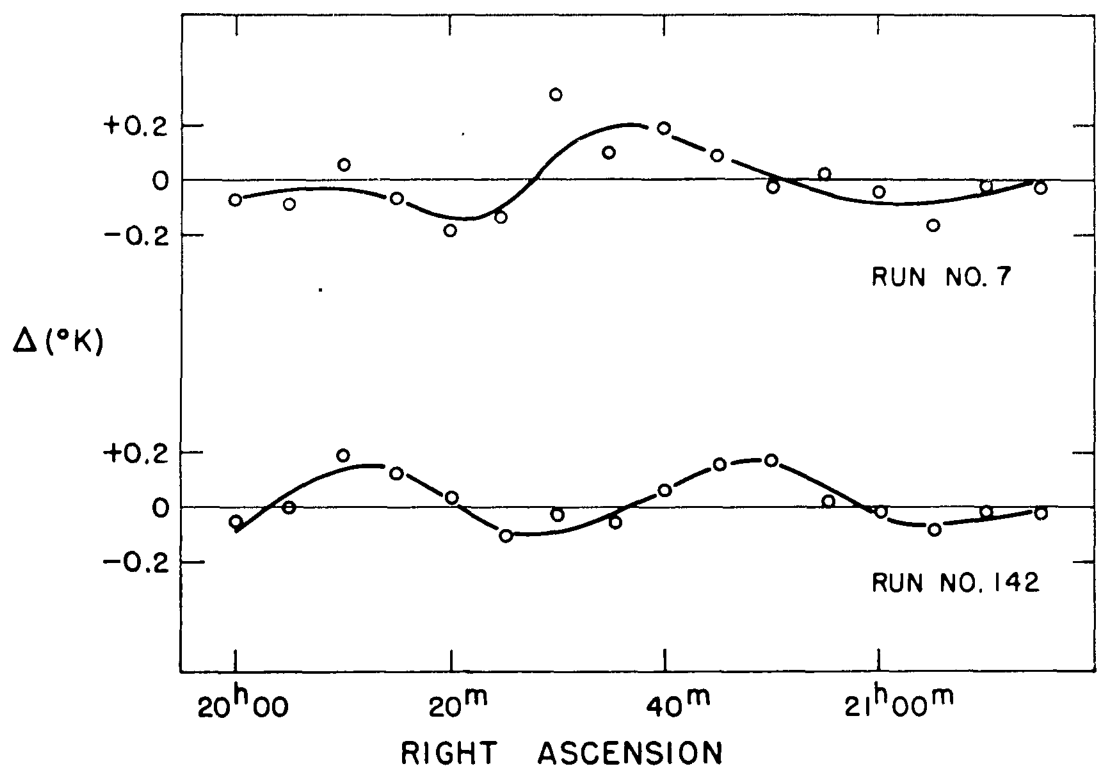


FIG. 2.—*Temperature corrections for two representative drift curves.*

4. *Observational results.*—The map so obtained is given in Fig. 3. The units for the contours are 0·87°K ($T_A$). Thirty-one possible sources, brighter condensations on the radio map, have been found in the region. These are indicated on the map as dots.

In Table I, these sources are listed, along with their positions, integrated flux densities, estimated sizes, background antenna temperatures, and identifications with sources found by other authors. No individual estimates of positional accuracy have been derived, but a probable error of $\pm 5'$ in declination and $\pm 0{\cdot}4^m$ in right ascension has been estimated. In some cases the evidence for the existence of a source is relatively weak and this is indicated by a source number in parenthesis.

The flux density of each source has been derived from the contours by comparing the integral of the antenna temperature over the source with the corresponding integral for Cygnus A. This ratio was then converted to flux

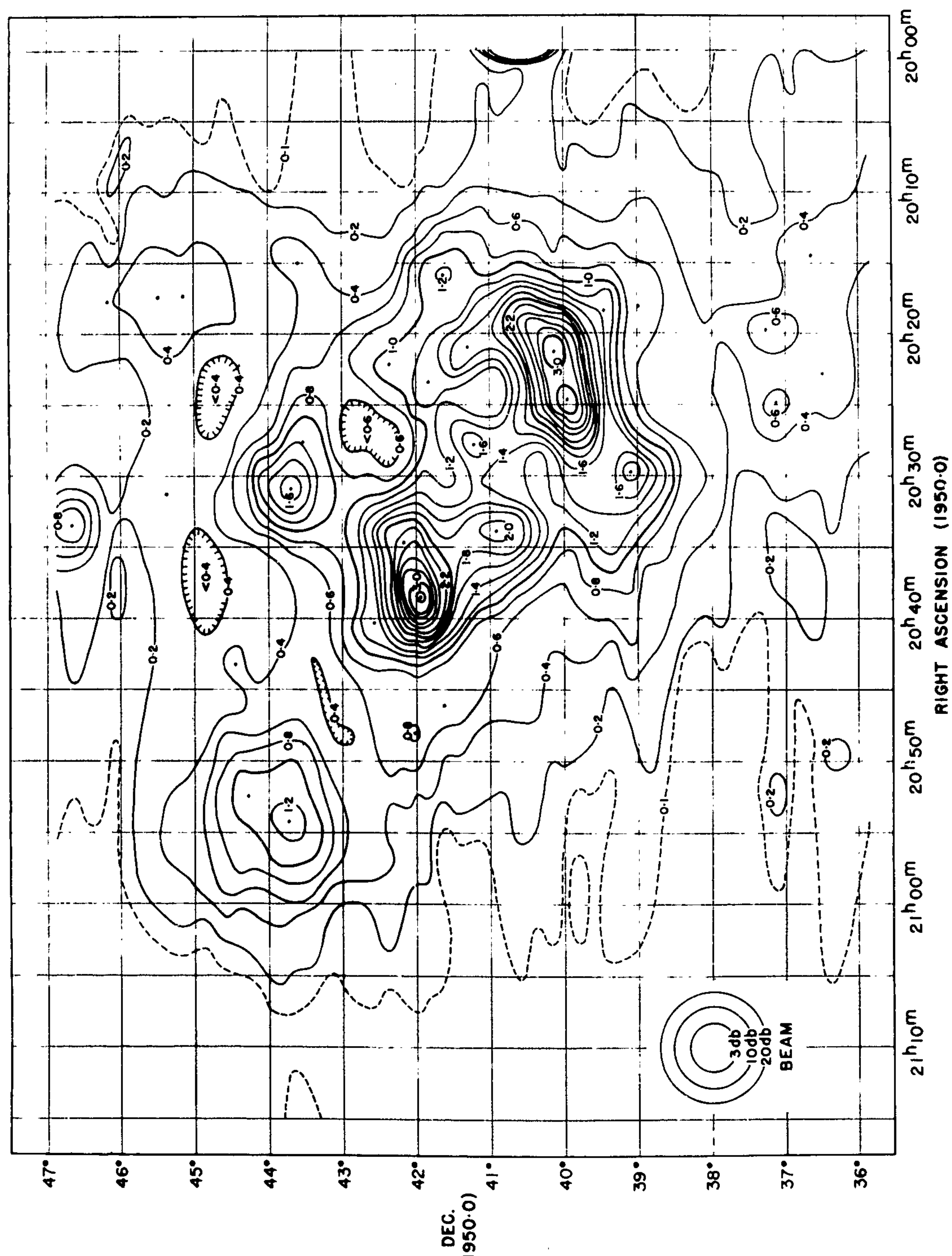


FIG. 3.—*Contours of antenna temperature at 3200 Mc/s for the Cygnus X region. Contour units are 0·87°K. Sources listed in Table I are indicated by dots.*

units using the value of 680 units for Cygnus A (5). To allow for the presence of nearby sources and an underlying continuum, the contours were first modified by the subtraction of a background contribution ($T_{bg}$). The magnitude of this at the source position is listed in the table. It is estimated that the flux values have a probable error of $\pm 30$ per cent. Values in parenthesis are peak flux values. The source diameters have been estimated from the integrated and peak flux densities, using the relationship, valid for Gaussian distributions,

$$S = S_{pk}[1 + (\theta_s^2)/(\theta_b^2)]$$

where $S$ is the integrated flux density, $S_{pk}$ is the peak flux density, $\theta_s$ is the source diameter and $\theta_b$ is the half-power beamwidth. The abbreviations in the identification with other lists represent the following: CTB, Wilson and Bolton (7); D, Drake (8); W, Westerhout (9); UBA, Müller (10); UBB, Altenhoff, *et al.* (11).

TABLE I

| No. | α (1950·0) h m | δ ° ′ | $S$ [$10^{-26}$ w.m.$^{-2}$ (c/s)$^{-1}$] | $\theta_s$ min. arc | $T_{bg}$ (°K) | Other Lists |
|---|---|---|---|---|---|---|
| (1) | 20 14·4 | 36 39 | 55 | 45 | 0·2 | CTB 87, UBA 10 |
| (2) | 20 15·0 | 43 36 | 55 | 55 | 0·1 | W 61 |
| 3 | 20 15·8 | 41 37 | 40 | <20 | 0·5 | D 1?, UBA 11, W 62 |
| 4 | 20 17·3 | 45 09 | (24) } 70 | ~1·5° | 0·2 } | CTB 88, UBA 13, W 63 |
| 5 | 20 17·4 | 45 29 | (18) | | 0·2 | |
| (6) | 20 17·7 | 46 11 | (12) | | 0·2 | |
| (7) | 20 18·1 | 38 56 | 10 | P | 0·5 } | W 65 |
| (8) | 20 18·3 | 39 28 | 15 | <20 | 1·0 | |
| 9 | 20 19·7 | 37 16 | 50 | 25 | 0·2 | CTB 90, UBA 15a, W 64? |
| 10 | 20 20·9 | 41 18 | 40 | P | 0·9 | CTB 89 |
| 11 | 20 21·2 | 40 08 | 315 | 50 | 1·0 | CTB 91, D 2, UBA 14a, W 66 |
| (12) | 20 22·1 | 42 22 | 28 | P | 0·5 | D 3, W 68c |
| (13) | 20 22·7 | 36 30 | 27 | 25 | 0·2 | UBA 15b |
| (14) | 20 23·3 | 41 50 | 20 | P | 0·8 | |
| 15 | 20 24·6 | 39 58 | 185 | 30 | 1·0 | D 4, UBA 14b, UBB 62, W 67 |
| 16 | 20 24·8 | 37 08 | 22 | P | 0·2 | UBB 63? |
| (17) | 20 27·5 | 43 33 | 35 | 25 | 0·7 | UBB 64 |
| 18 | 20 27·7 | 41 13 | 38 | P | 0·9 | CTB 92, D 5?, UBB 65, W 68b |
| 19 | 20 29·7 | 39 06 | 50 | P | 0·7 | CTB 94?, D 8, UBA 16, UBB 66?, W 69 |
| 20 | 20 30·8 | 43 42 | 90 | 30 | 0·5 | CTB 93, D 7, UBA 17, UBB 67, W 70 |
| (21) | 20 31·2 | 45 23 | 20 | 30 | 0·1 | W 74b? |
| 22 | 20 33·4 | 46 39 | 50 | P | 0·1 | CTB 95, UBA 19, UBB 68, W 71 |
| 23 | 20 33·8 | 40 56 | 95 | 25 | 0·9 | D 10, UBA 18?, UBB 69, W 73 |
| (24) | 20 34·6 | 42 11 | 80 | <20 | 1·0 | D 9, UBB 70, W 72? |
| 25 | 20 38·4 | 41 56 | 290 | 40 | 0·7 | CTB 96, D 11, UBA 20, UBB 71, W 75 |
| (26) | 20 40·2 | 42 35 | 12 | P | 1·0 | |
| 27 | 20 43·2 | 44 28 | 10 | P | 0·2 | |
| (28) | 20 46·0 | 41 37 | 15 | P | 0·3 | UBB 72? |
| 29 | 20 48·0 | 42 02 | 25 | P | 0·3 | W 79 |
| (30) | 20 52·4 | 44 17 | (18) } 270 | ~2° | 0·6 } | CTB 100, UBA 23, UBB 75, UBB 76, W 80 |
| 31 | 20 54·2 | 43 44 | (54) | | 0·3 | |

A comparison of flux values with those found in other surveys has not in general been attempted since different authors have used various background levels and different beamwidths. One source, however, is of particular interest.

5. *The γ-Cygni source.*—Source 11 in Table I ($\alpha = 20^h 21^m \cdot 2$, $\delta = 40°08'$) is sometimes called the γ-Cygni source, assuming it to be associated with the nebulosity surrounding γ-Cygni, an F8 star at a distance of about 100–200 parsecs (**8**). This identification has been questioned because of the inability of such a star to excite an emission nebula. In a detailed discussion of the Cygnus X region, Ikhsanov (**12**) has concluded that this source should be identified with a heavily obscured emission nebulae at a distance of 1000–1500 parsecs, perhaps part of the IC 1318 nebula. At frequencies below 1400 Mc/s, the γ-Cygni source has the greatest brightness temperature in the Cygnus X region, but at 3200 Mc/s we find that it is equalled or exceeded in brightness by two other sources (15 and 25 in Table I). Of particular interest here is source 15 at $\alpha = 20^h 24^m \cdot 6$, $\delta = 39°58'$. This has also been observed by Kuz'min *et al.* (**13**) and by others at lower frequencies (**8**, **9**, **14**). Its increase in brightness at high frequencies relative to the γ-Cygni source indicates a spectral difference between the two. Indeed there has been

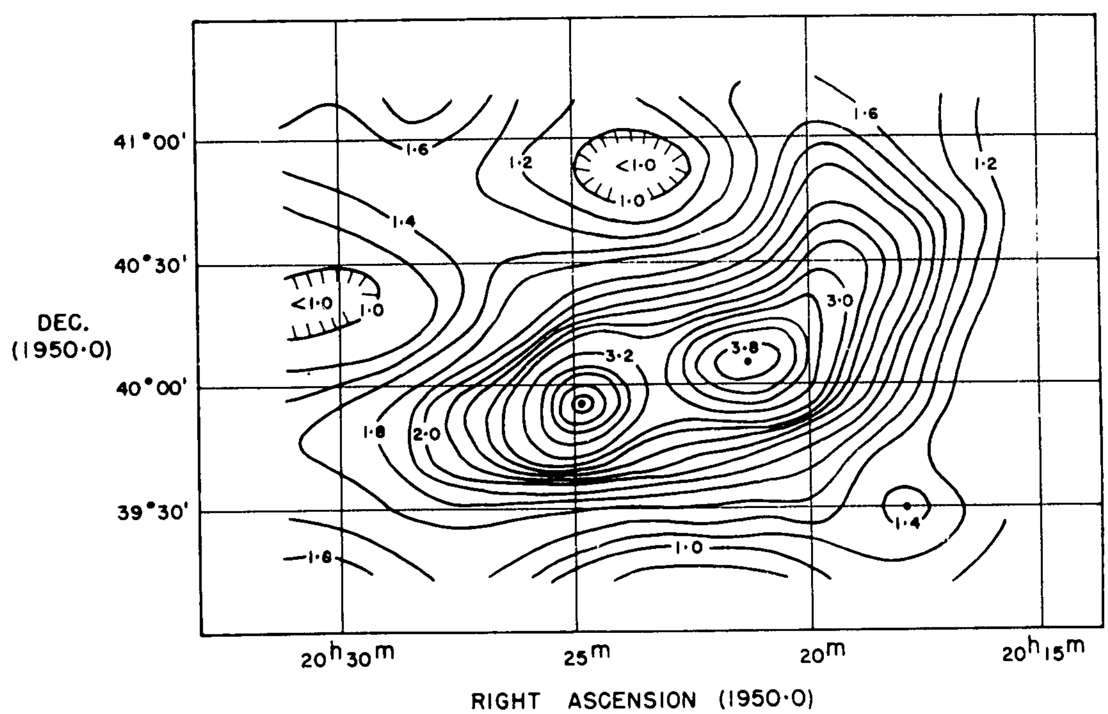


FIG. 4.—*Brightness temperature model of the γ-Cygni region. Contour units are 1·4°K.*

some previous evidence (**1**, **2**) that the γ-Cygni course is non-thermal. Because of this question, these two sources have been considered in more detail than the rest of the region.

They are just resolved by our relatively large beam and a brightness temperature model of the region has been calculated using an iteration process. This simple model, when convolved with the antenna pattern, yields an antenna temperature distribution agreeing with the observed values within the observational accuracy. Fig. 4 gives the corresponding contour map.

In the following, the source at $20^h 24^m \cdot 6$ will be referred to as Source A and

the $\gamma$-Cygni source as Source B. Only a few observations of the flux densities of these sources exist and these are listed in Table II. The values determined in the present investigation were obtained as described in the explanation of Table I, while the values at 610 Mc/s have been calculated in the same manner from preliminary observations obtained at the University of Illinois (14). It should be noted that Source B appears to have two components at that frequency and the quoted values refer to the sum of the two. A corresponding ridge extends to the north-west of the source in the present survey and has been included in our value for Source B.

TABLE II

| Frequency (Mc/s) | $S$ (Source A) [$10^{-26}$ w.m.$^{-2}$ (c/s)$^{-1}$] | $S$ (Source B) | Author |
|---|---|---|---|
| 610 | 220 ± 40 per cent | 555 ± 40 per cent | Yang and Swenson (14) |
| 960 | | (620 ± 25 per cent) | Wilson and Bolton (7) |
| 1390 | 170 ± 30 per cent | 590 ± 30 per cent | Westerhout (9) |
| 1396 | 160 ± 20 per cent | 400 ± 20 per cent | Drake (8) |
| 3200 | 185 ± 30 per cent | 315 ± 30 per cent | Present observations |

At 960 Mc/s, Wilson and Bolton (7) have listed only a total flux value for the combination of the two sources. From the flux values given by other observers for Source A (see Table II), a best-fit straight line indicates that the flux density at 960 Mc/s for Source A should be 180 ± 35 units. The corresponding value for Source B was obtained by subtracting this value from the published flux density.

In Fig. 5, the flux densities for these two sources have been plotted. A least-

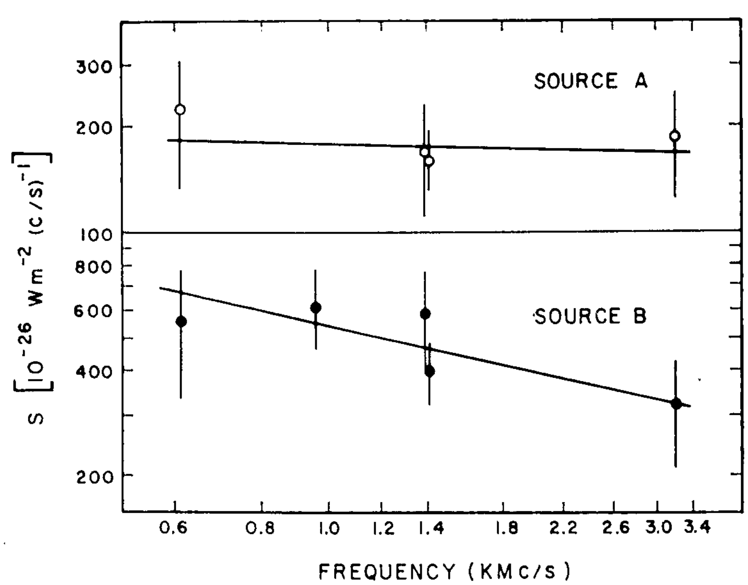


FIG. 5.—*Spectra of the two strong sources near $\gamma$-Cygni. Source A: companion of the $\gamma$-Cygni source. Source B: $\gamma$-Cygni source.*

square determination of their spectral indices ($\beta$) was made, yielding the slopes indicated in the figure. (The spectral index is defined by $S = k\nu^{\beta}$ where $k$ is a constant and $\nu$ is the frequency.) For Source A, $\beta = -0{\cdot}05 \pm 0{\cdot}30$, while for Source

B it was found that $\beta = -0{\cdot}44 \pm 0{\cdot}27$. The probable errors determined for the indices allow for the large probable errors in the observed flux values. From this it would appear that Source A radiates thermally while Source B is non-thermal.

6. *The supernova hypothesis.*—The large angular size of Source B and the non-thermal spectral index suggest an identification with a supernova remnant. The recent investigation of supernova remnants by Harris (**15**) forms the basis of the following discussion.

Present concepts of supernova remnant evolution lead to the conclusion that the surface brightness of such a source decreases with time (**16**). Harris extends this with the hypothesis that the spectral index of type II remnants approaches $+0{\cdot}5$ with time. From his evolutionary concepts it is unlikely that Source B is the remnant of a type I supernova. If it were such a source, its large angular size would place it only 50 parsecs from the Sun. Moreover, this would imply that the supernova occurred within the period 1000–1800 A.D. and would have been observed. Assuming then that the source is a type II supernova remnant, we may determine its true size from the empirical relation

$$r\,(\text{parsecs}) = 2{\cdot}57\,(1-2\beta)^{-2{\cdot}74}$$

derived by Harris, where $r$ denotes the mean radius of the source. This gives a mean diameter of 9 parsecs with probable error limits of 4–23 parsecs. The mean angular diameter of the source is $0{\cdot}80^\circ \pm 20$ per cent, defined as in the explanation of Table I. Since the source is irregular in form, this is considered the best estimate of angular size for the present purpose. Combining these values gives a distance to the source of 650 parsecs with probable error limits of 300–1650 parsecs. This would place the source either within the H II complex of Cygnus X or between it and the Sun (assuming a distance to the H II regions of 1·0–1·5 kpc [**12**, **17**]). A further check on the supernova hypothesis is a comparison of the surface brightness of Source B with its spectral index. In Fig. 5 of his paper, Harris relates the surface brightness at 960 Mc/s with spectral index. The spectrum determined in the present analysis yields a flux density at 960 Mc/s for Source B of $545 \pm 85$ units, and a surface brightness of $0{\cdot}30 \pm 0{\cdot}13$ flux units/min. arc$^2$. According to Harris, a type II supernova remnant with such a surface brightness should have a spectral index of $-0{\cdot}30 \pm 0{\cdot}04$. The observed spectral index is not in conflict with this.

7. *Concluding remarks.*—Certainly the observations at present are not sufficiently accurate to establish uniquely that Source B is a type II supernova remnant, but the possibility cannot be disregarded. In fact, according to Shklovsky's investigation of supernovae (**16**), one could expect to find the remnant of such an event amongst the OB associations required to ionize the Cygnus X complex. Unfortunately the excessive obscuration in this region will render extremely unlikely any optical confirmation of this hypothesis. If it is actually such a source, it is the third most intense yet discovered, surpassed only by Cassiopeia A and Vela X, Y, Z. In order firmly to establish the nature of the $\gamma$-Cygni source, more observations are required at higher resolution and at several frequencies. Future investigations at the Algonquin Radio Observatory will be in this direction.

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*Ottawa, Canada:*
1963 *July* 26.

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